Public Health Assessment

Initial/Public Comment Release

Enbridge pipeline release of heavy crude oil: Evaluation of people's risks from contact with the submerged oil located in the sediment of the Kalamazoo River

Prepared by
Michigan Department of Community Health

AUGUST 11, 2011

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Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

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Foreword

The Michigan Department of Community Health (MDCH) conducted this evaluation under a cooperative agreement with the federal Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR conducts public health activities (assessments/consultations, advisories, education) at sites of environmental contamination. The purpose of this document is to identify potentially harmful exposures and actions that would minimize those exposures. This is not a regulatory document and does not evaluate or confirm compliance with laws. This is a publicly available document that is provided to the appropriate regulatory agencies for their consideration.

The following steps are necessary to conduct public health assessments/consultations:

- Evaluating exposure: MDCH toxicologists begin by reviewing available information about environmental conditions at the site: how much contamination is present, where it is found on the site, and how people might be exposed to it. This process requires the measurement of chemicals in air, water, soil, or animals. Usually, MDCH does not collect its own environmental sampling data. We rely on information provided by the Michigan Department of Environmental Quality (MDEQ), U.S. Environmental Protection Agency (EPA), and other government agencies, businesses, and the general public.

- Evaluating health effects: If there is evidence that people are being exposed – or could be exposed – to hazardous substances, MDCH toxicologists then determine whether that exposure could be harmful to human health, using existing scientific information. The report focuses on public health – the health impact on the community as a whole.

- Developing recommendations: In its report, MDCH outlines conclusions regarding any potential health threat posed by a site, and offers recommendations for reducing or eliminating human exposure to contaminants. If there is an immediate health threat, MDCH will issue a public health advisory warning people of the danger, and will work with the appropriate agencies to resolve the problem.

- Soliciting community input: The evaluation process is interactive. MDCH solicits and considers information from various government agencies, parties responsible for the site, and the community. If you have any questions or comments about this report, we encourage you to contact us.

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www.michigan.gov/mdch-toxics

Acronyms and Abbreviations

ADAF	Age-Dependent Adjustment Factor
AE_d	Dermal Absorbance
AE_i	Gastrointestinal Absorbance
AF	Adherence Factor
AT	Averaging Time
ATSDR	Agency for Toxic Substances and Disease Registry
BW	Body Weight
CF	Conversion Factor
cm^2	Square centimeters
DNA	Deoxyribonucleic acid
ED	Exposure Duration
EF	Exposure Frequency
EPA	United States Environmental Protection Agency
EV	Event Frequency
F_i	Fraction of area impacted with submerged oil
F_{oil}	Fraction of petroleum residue that is oil
IRS	Sediment Ingestion
kg	kilograms
LT	Lifetime
MDCH	Michigan Department of Community Health
MDEQ	Michigan Department of Environmental Quality
mg	milligrams
ND	Not detected
PAHs	Polycyclic Aromatic Hydrocarbons
PHA	Public Health Assessment
RfD	Reference Dose
SA	Skin Surface Area
SF	Slope Factor
VOCs	Volatile Organic Chemicals

Summary

The Enbridge 6B pipeline oil release in July of 2010 affected close to 40 miles of the Kalamazoo River. While a majority of the heavy crude oil that was spilled has been recovered, oil remains in floodplains, on riverbanks, in the sediment at the bottom of the Kalamazoo River, and in Morrow Lake. As there are no clean-up criteria[1] for sediment, the Michigan Department of Community Health (MDCH) looked at the risk of health effects for people having contact with submerged oil located within the sediment. Sediment samples were taken from 19 different locations throughout the Kalamazoo River and Morrow Lake. These locations were identified during the spring of 2011 as having moderate to heavy amounts of submerged oil.

MDCH reached three conclusions regarding the remaining oil in the sediment:

1. *MDCH has concluded that contact with sediment containing submerged oil will not result in long-term health effects.* Non-cancer risk (hazard quotient) was calculated for the chemicals measured in the sediment. If the non-cancer risk (hazard quotient) values are less than 1.0, people are not expected to have long-term health effects from exposure to the chemicals. All non-cancer risk values were less than 1.0.

   Next steps: MDCH will continue to evaluate data collected on chemical levels in the sediment.

2. *MDCH has concluded that contact with sediment containing submerged oil will not result in a higher than normal risk of cancer.* Cancer risk was calculated for carcinogens measured in sediment samples. Cancer risk calculations estimate the theoretical number of additional cases of cancer from exposure to these chemicals. This is in addition to the background rate of cancer. Michigan's overall cancer rate is 489 individuals in 100,000[2], which is roughly one individual in 200. If cancer risk calculations, based on exposure to chemicals in the sediment, estimate an increase of one additional case in 10,000, the cancer rate is considered higher than normal. Cancer risk values for all samples were less than one extra individual in 10,000.

   Next steps: MDCH will continue to evaluate data collected on chemical levels in the sediment.

3. *MDCH has concluded that contact with sediment containing submerged oil, oil remaining in floodplains and on riverbanks (such as tar patties), or sheen on the water could cause short-term health effects, such as skin irritation.* Contact with chemicals in the crude oil can cause skin irritation, such as rashes or red patches of skin. Some people may be more sensitive than others, and may develop skin irritation with a shorter exposure or from exposure to a small amount of residual oil. Contact with the remaining oil should be avoided.

[1] Michigan Department of Environmental Quality Part 201 Criteria
[2] This cancer rate was from 2007 data and can be found at http://www.mdch.state.mi.us/pha/osr/Cancer/stateinc.asp?CDxID=IncTrendsTotal.

Next steps: MDCH will work with local health departments and community members to provide health protective information.

Purpose and Health Issues

The recovery and clean-up of crude oil has been on-going in the year since the Enbridge Energy Partners, LLP (Enbridge) pipeline release. A majority of the oil that was floating on the surface of the water and on riverbanks has been collected. Some oil still remains in overbank areas and submerged in sediment at the bottom of the Kalamazoo River and Morrow Lake. Current oil collection efforts are focused on removing this remaining oil. The U.S. Environmental Protection Agency (EPA) and the Calhoun County Public Health Department have asked that MDCH review the risk from people touching or accidentally eating the remaining oil. A person could accidentally eat the oil if they don't wash their hands well enough before eating or preparing food, or by not thoroughly cleaning food taken from their gardens[3]. MDCH calculated the non-cancer and cancer risk from contact with the submerged oil in the sediment. The results and conclusions in this health assessment are for public health purposes only and do not show compliance with, or satisfy, EPA or Michigan Department of Environmental Quality (MDEQ) regulations or requirements. The results review the theoretical risk to humans only and do not look at the risk to wildlife or provide any ecological assessment. This evaluation does not include any discussion of breathing the chemicals from the residual material, eating fish from the Kalamazoo River, or contact with surface water. These topics will be evaluated in a separate health assessment.

Background

On July 26, 2010, more than 800,000 gallons of crude oil flowed into Talmadge Creek, a tributary of the Kalamazoo River. The oil was from a 30-inch pipeline near the city of Marshall, Calhoun County, Michigan, operated by Enbridge. Enbridge reported the spill to the National Response Center, which notified the EPA, among other agencies.

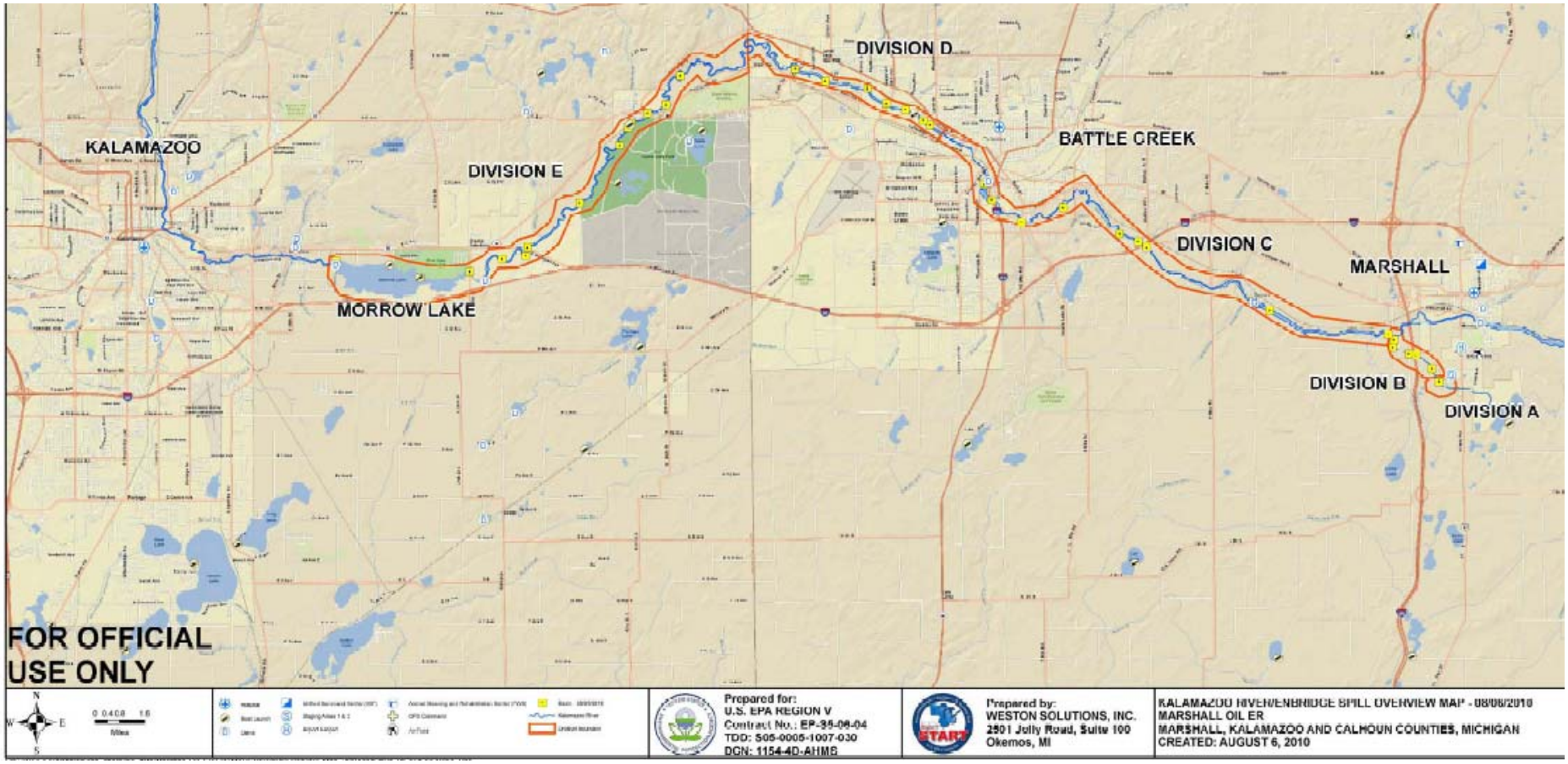
The EPA was the lead agency for response to this spill and on July 27, the Federal On-Scene Coordinator and Incident Commander issued the EPA Removal Order. Using guidelines of the Incident Command System[4], a Unified Command was established later that week. Members of the Unified Command included federal, state and local agencies, along with Enbridge representatives. At the request of the EPA Incident Commander, MDCH staff deployed to the Command Center to provide public health support.

The spilled oil was eventually contained at Morrow Lake, which is more than 30 miles downstream from the spill. (See Figure 1 for a map of the oil spill.) At the time of the spill, Talmadge Creek and the Kalamazoo River were between 25- and 50-year flood levels due to the

[3] Residents who live along the river may irrigate their garden with water from the river. Sediment from the river could end up in their garden.

[4] The Incident Command System is a management system for incidents of all sizes and types. This system is used when one agency is responding to an incident and can be scaled up for when many agencies are responding to an incident.

Figure 1: Overview of the areas of Talmadge Creek and the Kalamazoo River impacted by the July 2010 oil spill (Calhoun and Kalamazoo Counties, Michigan). Divisions A through E are arbitrary divisions created to assist with the response to the spill. Map was taken from the EPA's Response to the Enbridge Oil Spill website (http://www.epa.gov/enbridgespill/images/enbridge_overview_map_20100806.pdf).



rain that had fallen during the previous days. Because the river and creek were at high water levels, oil flowed into floodplains, riverbanks (overbank areas), and wetlands.

Oil can still be found in the floodplains, riverbanks, and on the bottom of the river. Some of the oil in the floodplains and riverbank areas weathered and became asphalt-like tiles on the soil. These asphalt-like tiles, also called "tar patties," range from being soft and clay-like to hard, similar to an asphalt parking lot. It is possible that oil may leak out from these tar patties and could get on the skin of people handling them.

Oil that remains on the bottom of the river and lake, also called submerged oil, may rise to the surface when the sediment is disturbed. This results in oil sheen and tar balls on the surface of the water. Oil recovery efforts are focusing on removal of the submerged oil and tar patties throughout the impacted areas of the Kalamazoo River and Morrow Lake.

The areas with tar patties and submerged oil were identified during the spring 2011 reassessment of the impacted areas. Teams of people walked the floodplains and riverbanks to identify any sheen or remaining oil, such as tar patties. Other teams used a method called *poling* to search for oil on the bottom of the Kalamazoo River and Morrow Lake. Poling is a method where long poles are used to stir up the sediment on the bottom of the river. Locations where submerged oil remained were identified if oil sheen or tar globules floated to the surface. Areas were identified as having no, light, moderate, or heavy submerged oil amounts.

Areas with moderate to heavy submerged oil are areas that have the greatest amounts of remaining oil. Higher levels of oil-related chemicals are located in these areas. Sediment samples were collected from areas identified as having moderate to heavy amounts of submerged oil to provide information on the maximum levels of chemicals present.

Discussion

As no sediment screening levels have been set by the State of Michigan, non-cancer (hazard quotient) and cancer risk calculations were done to assess the potential health effects for people having contact with the submerged oil in the sediment. Non-cancer risk was calculated for chemicals that are not considered cancer-causing (carcinogens) or do not have a cancer toxicity value (slope factor). Non-cancer risk evaluates the potential of people having long-term health effects, but not cancer, from exposure to a chemical. Long-term health effects include health effects that occur after an exposure and may continue after that exposure has ended. This evaluation does not include health effects that may happen immediately, such as skin irritation due to touching the residual oil materials.

Theoretical cancer risk was calculated for the chemicals that are considered cancer-causing and that have a cancer toxicity value. Cancer risk values calculate the theoretical number of extra cases of cancer over the background rate from exposure to these chemicals. A higher than normal risk of cancer, for this evaluation, was greater than one extra case of cancer in population of 10,000[5]. Typically used ranges of cancer risk are from one extra individual with cancer in 10,000 (1E-04) to one extra individual in 1,000,000 (1E-06). Michigan's overall cancer rate is about one

[5] The MDEQ has a required cancer risk of no greater than one extra individual in 100,000 over the background incidence of cancer (MDEQ 2005) for regulatory purposes.

individual in 200[6].When more than one extra person out of 10,000 people is calculated to develop cancer, this signals that exposure to the chemicals in the remaining oil may be a problem necessitating further evaluation and possible actions to stop or reduce harmful exposures.

Environmental Contamination

Sediment samples (34 total) from 19 areas with moderate to heavy amounts of submerged oil were collected throughout the Kalamazoo River and the Morrow Lake delta (between mile post 4.50 and 37.25). Crude oil related chemicals were measured in the samples. The chemicals measured were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), four metals (beryllium, vanadium, nickel, and molybdenum), and total petroleum hydrocarbons (gasoline range organics, diesel range organics, and oil range organics).

Table 1 shows the levels of chemicals measured in those sediment samples. Some chemicals were not detected above the reporting limit. For example, beryllium was not detected in the samples. The maximum levels (1 milligram per kilogram [mg/kg]) for beryllium in Table 1 was the highest levels that could be measured for the samples[7]. Actual levels of beryllium in samples are lower than those levels.

Chemical levels in Table 1 were used in the calculation of non-cancer and cancer risk for people that may have contact with submerged oil in the sediment. If the chemical was detected in a sample, that result was used for the sample. If the chemical was not detected in the sample, half of the reporting limit (the lowest level of the chemical that could be detected in the sample) was used. For example, toluene was not detected in any sample. The maximum (1.5 mg/kg) levels for toluene in Table 1 were the reporting limits for an individual sample. Half of that value (0.75 mg/kg) was used in the calculation. The use of half of the reporting limit is recommended when the chemical may be found at the site (EPA 1989).

Nine of the chemicals in Table 1 (2-methylnaphthalene, p-isopropyl toluene, cyclohexane, 1,2,3-trimethylbenzene, m & p-xylene, o-xylene, diesel range organics [C10-C20], gasoline range organics [C6-C10], and oil range organics [C20-C34]) were not included in the risk calculations. Several of the chemicals did not have toxicity values (necessary information for the risk calculations) available. Calculations for m- & p- and o-xylene were not done individually as xylenes were evaluated together. The diesel range organics (C10-C20), gasoline range organics (C6-C10), and oil range organics (C20-C34) were not included in the calculations as there are no toxicity values for weathered mixtures of hydrocarbons (Edwards et al. 1997).

[6] This cancer rate of 1 in 200 (489.1 in 100,000 on the website) was from 2007 data and can be found at http://www.mdch.state.mi.us/pha/osr/Cancer/stateinc.asp?CDxID=IncTrendsTotal.

[7] Because of interferences from the remaining oil in the sample, the reporting limits varied for the samples. The highest (maximum) reporting limit or the highest detection, if there was one, was presented in Table 1.

Table 1: Chemicals measured in the 34 sediment samples (in milligrams per kilogram [mg/kg]) from the Kalamazoo River (Calhoun and Kalamazoo Counties, Michigan) (AECOM 2011a)

Chemical	Maximum level[a] (mg/kg)
1,2,3-Trimethylbenzene[b]	1.5[c]
1,2,4-Trimethylbenzene	1.5[c]
1,3,5-Trimethylbenzene	1.5[c]
2-Methylnaphthalene[b]	0.42[c]
Acenaphthene	0.33[c]
Acenaphthylene	0.33[c]
Anthracene	0.33[c]
Benzene	1.5[c]
Benzo(a)anthracene	0.51
Benzo(a)pyrene	0.52
Benzo(b)fluoranthene	0.56
Benzo(g,h,i)perylene	0.33[c]
Benzo(k)fluoranthene	0.37
Beryllium	1[c]
Chrysene	0.46
Cyclohexane[b]	1.5[c]
Dibenzo(a,h)anthracene	0.33[c]
Diesel Range Organics (C10-C20)[b]	440
Ethylbenzene	1.5[c]
Fluoranthene	0.97
Fluorene	0.33[c]
Gasoline Range Organics (C6-C10)[b]	10[c]
Indeno(1,2,3-c,d)pyrene	0.33[c]
Isopropyl benzene	1.5[c]
m & p-Xylene[b]	3[c]
Molybdenum	2.4
Naphthalene	0.33[c]
Nickel	36
n-Propylbenzene	1.7
Oil Range Organics (C20-C34)[b]	1900
o-Xylene[c]	1.5[c]
Phenanthrene	0.48
p-Isopropyl toluene (p-Cymene)[b]	1.5[c]
Pyrene	0.78
sec-Butylbenzene	1.5[c]
Toluene	1.5[c]
Vanadium	42
Xylenes	1.6[c]

a = The maximum for a chemical may be the reporting limit (the lowest value the instrument could detect for that sample) or the highest amount detected in a sample.
b = The chemical was not included in the risk calculations.
c = The chemical was not detected above the reporting limit in any of the samples.

Exposure Pathways Analysis

There are five things to consider when deciding if a person may be exposed to a chemical, also known as an *exposure pathway*: (1) where is the chemical coming from, (2) what in a person's environment has been contaminated, (3) is there a way a person might come into contact with the chemical, (4) how they might come into contact with the chemical, and (5) who might be exposed to it. An exposure pathway is complete if it is expected or there is proof that all five elements are present. Table 2 describes human exposure to chemicals in the Kalamazoo River and Morrow Lake (Calhoun and Kalamazoo Counties), from recreational use of the river. The breathing in of chemicals from the remaining oil was not included in this health assessment. People may still smell odors from the remaining oil and that route of exposure (inhalation) will be addressed in a separate health assessment. Eating fish from the Kalamazoo River and contact with surface water will also be addressed in a separate document.

Table 2: Exposure pathway for residents of and visitors to the areas of the Kalamazoo River and Morrow Lake (Calhoun and Kalamazoo Counties), Michigan, impacted by the July 2010 Enbridge pipeline release of heavy crude oil.

Source	Environmental Medium	Exposure Point	Exposure Route	Exposed Population	Time Frame	Exposure
Enbridge pipeline release of heavy crude oil	Submerged oil in the sediment	Sediment	Ingestion, dermal contact, and inhalation	Residents along and Visitors to the Kalamazoo River and Morrow Lake	Past Present Future	Eliminated Potential Potential
	Oil in the soil (weathered or free product)	Soil with residual oil, such as "tar patties" or any remaining oil	Dermal contact, incidental ingestion, and inhalation	Residents along and Visitors to the Kalamazoo River and Morrow Lake	Past Present Future	Eliminated Potential Potential
	Submerged oil in the sediment	Oil sheen and tar balls in surface water	Dermal contact, incidental ingestion, and inhalation	Residents along and Visitors to the Kalamazoo River and Morrow Lake	Past Present Future	Eliminated Potential Potential

If a person were to wade through areas with submerged oil, such as the Morrow Lake delta, oil sheen or tar balls may occur around that person from suspension of the submerged oil. In some cases, clothing or jewelry could keep oil in contact with the skin. This could increase a person's exposure to the chemicals in the remaining oil.

Exposure scenario for calculation of risk

MDEQ and MDCH toxicologists looked at ways people use the river and the lake. People who use the river and lake the most would be expected to come into contact with the oil most often. This scenario considers people who live along the Kalamazoo River and Morrow Lake and may use the river or lake a lot. People who live along the river may have sediment from recreational river activities in their yards. They could also touch or accidentally eat the dirt daily throughout

the spring and summer seasons. They may also go canoeing, kayaking, or do other recreational activities along and in the river and lake.

The exposure scenario used in this health assessment represented season-long daily use of the Kalamazoo River by people that live along the river. The values were selected to represent the greatest amount of exposure that residents along the river are expected to have. Individuals that use the river less often would have a lower exposure and lower risk than the people who live on the bank or shores and use the river or lake daily.

These exposure scenario includes:

- the number of days people are using the Kalamazoo River (150 days were selected as representing May through October, which are the most likely months that people would have contact with the sediment),
- the amount of submerged oil that is present in the impacted area of the Kalamazoo River sediment (the quarter mile of the Morrow Lake delta with the heaviest submerged oil was used to represent the entire river),
- the number of years an individual may be exposed to the chemicals in the sediment (all years within the age range were included),
- the entire amount of sediment or soil material (sediment on the banks or in a person's yard) that a person may accidentally eat in a day, and
- the amount of sediment or soil material (sediment on the banks or in a person's yard) that a person may have stuck to his or her skin after touching it (values for children playing in wet soil or adults gardening were used).

Toxicological Evaluation

Non-cancer and cancer risk was calculated using the chemical levels from the sediment samples.

Non-cancer risk (hazard quotients)

Non-cancer risk (hazard quotient) was calculated for twenty-two chemicals. A hazard quotient is the amount of a chemical a person is exposed to, divided by the amount of the chemical that is *not* expected to cause health effects.

- If the non-cancer risk is less than 1.0, a person is exposed to the amount of the chemical that is less than the amount that is *not* expected to cause health effects. No further evaluation of this exposure is needed.
- If the non-cancer risk is 1.0, a person is exposed to the same amount of the chemical that is not expected to cause health effects. No further evaluation of this exposure is needed.
- If the non-cancer risk is greater than 1.0, a person is exposed to the amount of the chemical that is greater than the amount that is *not* expected to cause health effects. This does not automatically mean that people will have health effects, but that the exposure may need to be reviewed further as exposure to a larger amount of chemical is occurring.

The equation to calculate non-cancer risk includes both touching and accidently eating the oil. The equations and variables used for these calculations are shown in Appendix A.

Table 2 shows the non-cancer risk for children, ages 1-6. Children were selected as the most sensitive group for exposure to these chemicals. Children are more sensitive to chemicals due to

their greater exposures (based on both size and activities) and the fact that their bodies are still developing.

The maximum hazard quotients for each chemical are approximately 100 times less than 1.0. Even if the hazard quotient for each chemical in a sample is added up, the maximum value is more than 25 times lower than 1.0[8]. This shows that small children are not expected to get sick from the chemicals in the oil at these levels.

Table 3: Non-cancer risk for a child, ages 1-6, with frequent exposure to chemicals in the sediment in the Kalamazoo River (Calhoun and Kalamazoo Counties, Michigan).

Chemical	Maximum Hazard Quotient
1,2,4-Trimethylbenzene	0.000056
1,3,5-Trimethylbenzene	0.000056
2-Methylnaphthalene	0.00054
Acenaphthene	0.000029
Acenaphthylene	0.00024
Anthracene	0.0000057
Benzo(g,h,i)perylene	0.00055
Beryllium	0.00052
Ethylbenzene	0.000078
Fluoranthene	0.00025
Fluorene	0.000043
Isopropyl benzene	0.000071
Molybdenum	0.0014
Naphthalene	0.000086
Nickel	0.011
n-Propylbenzene	0.0016
Phenanthrene	0.00070
Pyrene	0.00027
sec-Butylbenzene	0.00071
Toluene	0.000097
Vanadium	0.024
Xylenes	0.0000046
Total Hazard Index per sample (all chemicals in a sample)[a]	0.039

a = This value assumes that all of the chemicals have the same toxicity endpoint and the risk is cumulative, which is not necessarily the case.

[8] Adding the hazard quotients (non-cancer risk) for all chemicals in a sample assumes that all chemicals cause the same health effects. This is not necessarily the case. These summaries are provided to give the most conservative presentation of exposure to all of the non-carcinogenic chemicals measured in the sample.

Cancer risk for benzene

The theoretical cancer risk was calculated for benzene[9]. Cancer risk values calculate the theoretical number of people that may develop cancer from exposure to these chemicals. A higher than normal risk of cancer, for this evaluation, was greater than one extra individual in 10,000. This extra individual with cancer is in addition to the background levels of cancer. Michigan's overall cancer rate is about one individual in 200[10]. When more than one extra person out of 10,000 people is calculated to develop cancer, this signals that exposure to the chemicals in the remaining oil may be a problem. The cancer risk equations include exposure from touching and accidentally eating the oil. The equation and specific variables used in the calculations are shown in Appendix A.

Table 3 presents the cancer risk for adults and children, ages 1-6, exposed to benzene from the submerged oil. As this calculation was for cancer risk, adults were included in the calculation. Children, ages 1-6, were included as the most sensitive age range expected to potentially have contact with the submerged oil.

The theoretical cancer risk for exposure to benzene was found to be much less than one extra individual with cancer in 10,000, and also less than one extra individual with cancer in 100,000 (the cancer risk used in MDEQ regulations) for each sample. See Table 3.

Table 4: Theoretical cancer risk from benzene for adults and children, ages 1-6, with frequent exposure to chemicals in the sediment in the Kalamazoo River (Calhoun and Kalamazoo Counties, Michigan).

Benzene	Maximum cancer risk
Adult cancer risk	3.5 in 100,000,000 (3.50E-08)
Child (ages 1-6) cancer risk	1.48 in 10,000,000 (1.48E-07)
Total cancer risk for each sample[a]	1.83 in 10,000,000 (1.83E-07)

a = The adult and child cancer risk are added together.

Cancer risk for Polycyclic Aromatic Hydrocarbons (PAHs)

The theoretical cancer risk was calculated for seven PAHs. An additional variable is included in the calculations for children ages 0 to 2, 2-6, and 6-16.

A higher than normal risk of cancer, for this evaluation, was greater than one extra individual in 10,000. This extra individual with cancer is in addition to the background levels of cancer. Michigan's overall cancer rate is about one individual in 200**Error! Bookmark not defined.**.When more than one extra person out of 10,000 people is calculated to develop cancer,

[9] The EPA has not yet included benzene on its list of chemicals recommending use of Age-Dependent Adjustment Factors for cancer risk calculations (as of July 29, 2011). See http://www.epa.gov/oswer/riskassessment/sghandbook/chemicals.htm for the list.

[10] This cancer rate was from 2007 data (489.1 individuals in 100,000 listed on the website) and can be found at http://www.mdch.state.mi.us/pha/osr/Cancer/stateinc.asp?CDxID=IncTrendsTotal.

this signals that exposure to the chemicals in the remaining oil may be a problem. The cancer risk equations include exposure from touching and accidentally eating the oil. The equation and specific variables used in the calculations are in Appendix A.

Table 4 presents the theoretical cancer risk for adults and three child age groups (0-2, 2-6, and 6-16) from exposure to PAHs. The cancer risks for these four groups were added together for each chemical in a sample.

Maximum cancer risks for each chemical were lower than one extra case of cancer over background in a population of 10,000 (1E-04) similarly exposed. These chemicals are considered to act the same in the body. Because of this, the cancer risk for each of the chemicals in a sample can be added together. The maximum total cancer risk (for each sample) was lower than one extra individual with cancer in 10,000 (1E-04).

Table 5: Theoretical cancer risk for Polycyclic Aromatic Hydrocarbons (PAHs) calculated for adults and children, ages 0-2, 2-6, and 6-16, with frequent exposure to chemicals in the sediment in the Kalamazoo River (Calhoun and Kalamazoo Counties, Michigan).

Chemical	Maximum cancer risk
Benzo(a)anthracene[a]	3.09 in 1,000,000 (3.09E-06)
Benzo(a)pyrene[a]	3.15 in 100,000 (3.15E-05)
Benzo(b)fluoranthene[a]	3.29 in 1,000,000 (3.39E-06)
Benzo(k)fluoranthene[a]	2.24 in 10,000,000 (2.24E-07)
Chrysene[a]	2.78 in 100,000,000 (2.78E-08)
Dibenzo(a,h)anthracene[a]	1.83 in 100,000 (1.83E-05)
Indeno(1,2,3-c,d)pyrene[a]	1.83 in 1,000,000 (1.83E-06)
Total cancer risk for each sample[b]	4.83 in 100,000 (4.83E-05)

a = Calculated cancer risks for adults and the three child age groups were added together for each chemical.
b = This value is a cumulative risk for all of the chemicals.

People will not have long-term harm from contact with levels of chemicals measured in the submerged oil. However, touching the submerged oil, tar patties, and oil sheen may cause skin irritation. Contact with the remaining oil should be avoided when possible.

Children's Health Considerations

Children may be at greater risk than adults when exposed to certain hazardous substances. Children play outdoors and are more likely to put their hands in their mouths or touch their faces. Doing so increases their chance of exposure. Young children are also shorter than adults; they breathe dust, soil, and vapors close to the ground. A child's lower body weight and higher intake rate result in a greater dose of hazardous chemicals compared to their weight. If toxic exposure levels are high enough during critical growth stages, the developing body systems of children may be damaged.

The remaining oil might be of interest to children. The tar patties are like tiles on the soil and some are pliable and clay-like. If children play with the patties, skin irritation could occur. Oil sheen on the water is shiny and could be rainbow-colored. This sheen may also be of interest to children and may also result in skin irritation. Children should not touch the remaining oil.

Conclusions

- MDCH has concluded that contact with sediment containing submerged oil will not result in long-term health effects. Non-cancer risk (hazard quotient) was calculated for the chemicals measured in the sediment. If the non-cancer risk (hazard quotient) values are less than 1.0, people are not expected to have long-term health effects from exposure to the chemicals. All risk values were lower than 1.0.

- MDCH has concluded that contact with sediment containing submerged oil will not result in a higher than normal theoretical risk of cancer. Cancer risk for was calculated for carcinogens measured in sediment samples. Cancer risk values calculate the number of additional individuals that may develop cancer from exposure to these chemicals. This is in addition to the background rate of cancer. Michigan's overall cancer rate is about one individual in 200[11]. A higher than normal risk of cancer, for this evaluation, was greater than one extra individual in 10,000. Cancer risk values for all samples were less than one extra individual in 10,000.

- MDCH has concluded that contact with sediment containing submerged oil, oil remaining in floodplains and on riverbanks (tar patties), or sheen on the water could cause short-term health effects, such as skin irritation. Chemicals in the crude oil can cause skin irritation, resulting in rashes or red patches of skin. Some people may be more sensitive than others, and may develop skin irritation with a shorter exposure or from exposure to a small amount of residual oil. Contact with the remaining oil should be avoided.

[11] This cancer rate was from 2007 data (489.1 individuals in 100,000 listed on the website) and can be found at http://www.mdch.state.mi.us/pha/osr/Cancer/stateinc.asp?CDxID=IncTrendsTotal.

Recommendations

- People should avoid contact with residual oil from the July 2010 Enbridge pipeline release. If people get oil on their skin, they should wash with soap and water. There is no need to use strong or harsh soaps or detergents.
- Oil from the July 2010 Enbridge pipeline release should be recovered, if possible. The EPA and MDEQ are the agencies overseeing the oil recovery and remediation.

Public Health Action Plan

- MDCH will work with local health departments and community members to provide health protective information and is in the process of evaluating other ways people may be exposed to the chemicals in the remaining crude oil.

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Certification

This Health Assessment was prepared by the Michigan Department of Community Health under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures. Editorial review was completed by the cooperative agreement partner.

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The Division of Health Assessment and Consultation, ATSDR, has reviewed this public health assessment and concurs with the findings.

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Appendix A: Sediment risk assessment calculations:

Equations in Annex F: Human Health Considerations (OSAT-2 2011) were used to calculate the non-cancer (hazard quotient) and theoretical cancer risk from people in direct contact with and ingesting submerged oil in the sediment (dermal and oral exposure dose). The equations in Annex F were based on the Florida Department of Health's Human Health-Based Screening Levels for Petroleum Products Impacting Gulf Coastal Waters and Beach Sediments (FDOH 2010). One equation was for the hazard quotient and two equations were for cancer risk. One of the cancer risk equations included Age-Dependent Adjustment Factors (ADAFs) in the calculations. The EPA has a list of 16 chemicals, including PAHs[12], for which ADAFs are recommend for inclusion in the cancer risk calculations (EPA 2005).

Unrestricted exposure scenario

An unrestricted exposure scenario was used for these equations. Exposure parameters represented season-long daily use of the Kalamazoo River by residents that live along the river. The exposure parameters were selected to represent the most conservative exposure (the greatest exposure that is reasonably expected to occur) that residents along the river are expected to have. These exposure parameters include:

- the number of days people are using the Kalamazoo River (Exposure Frequency),
- the amount of submerged oil that is present in the impacted area of the Kalamazoo River sediment (Fraction of the area impacted),
- the number of years an individual may be exposed to the chemicals in the sediment,
- the amount of sediment or soil material that a person may ingest for the day (Sediment ingestion), and
- the amount of sediment or soil material that may adhere to a person's skin (Adherence factor).

Hazard Quotient (Non-Cancer Risk)

The hazard quotient is a ratio of the amount of a chemical that a person is exposed to a reference dose. A reference dose is the amount of a chemical that is *not* expected to cause health effects for a lifetime of exposure (these health effects do not include cancer).

- If the hazard quotient is less than 1.0, the amount of chemical a person is exposed to is less than the reference dose.
- If the hazard quotient is equal to 1.0, the amount of chemical a person is exposed to is equal to reference dose.
- If the hazard quotient is greater than 1.0, the amount a person is exposed to is greater than the reference dose. This does not mean that a person will have health effects from that chemical, but that exposure to that chemical should be evaluated further.

The hazard quotient was calculated for children, ages 1-6, using Equation 1. Children are more sensitive to chemicals due to their greater exposures (based on both size and activities that may

[12] Guidance for these carcinogens can be found at http://www.epa.gov/oswer/riskassessment/sghandbook/chemicals.htm.

cause them to ingest more or have more soil adhered to their skin) and the fact that their bodies are still developing.

Equation 1: Hazard Quotient (non-cancer risk) - Ingestion and dermal risk equation[13]

$$HQ = \frac{Concentration \times F_{oil} \times F_i \times EF \times ED \times [IRS + (SA \times AF \times \frac{1}{AE_i} \times AE_d)] \times \frac{1}{RfD} \times CF}{AT \times ED \times BW}$$

A hazard quotient was calculated for these chemicals:

Metals:	Organic chemicals:	
Beryllium	2-Methylnaphthalene	Pyrene
Molybdenum	Acenaphthene	1,2,4-Trimethylbenzene
Nickel	Acenaphthylene	1,3,5-Trimethylbenzene
Vanadium	Anthracene	Ethylbenzene
	Benzo(g,h,i)perylene	Isopropyl benzene
	Fluoranthene	n-Propylbenzene
	Fluorene	sec-Butylbenzene
	Naphthalene	Toluene
	Phenanthrene	Xylenes

The variables used in Equation 1 are presented in Table A-1 and described below. These variables are either an exposure parameters or are chemical-specific values necessary to evaluate the chemical in the sample.

[13] For the result to be unitless, skin surface area (SA) units need to cm^2/event and a variable for 1 event/day need to be included.

Table A-1: Variables for calculation of the Hazard Quotient for children, ages 1-6, and an unrestricted exposure scenario.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - child	years	6
Sediment Ingestion (IRS) - child	milligram per day (mg/day)	200
Skin surface area (SA) - child	square centimeters (cm^2)	2,670
Adherence Factor (AF) - child	milligram per square centimeter (mg/cm^2)	2.98
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Reference dose (RfD)	milligram per kilogram-day (mg/kg-day)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Body weight (BW) - child	kilograms (kg)	15

Variable descriptions are below:

- Concentration refers to the levels of the chemicals measured in each of the sediment samples. Concentration of each chemical is specific to the sample. If a chemical was detected above the reporting limit, that value was used in the calculations. If a chemical was not detected above the reporting limit, one-half of the reporting limit for that sample was used for the calculations.
- The fraction of the petroleum residue that is oil (F_{oil}) was used in the Gulf of Mexico oil spill to compensate for having analytical data on the oil and not the levels of chemicals present in the material on the beaches (OSAT-2 2011). Chemical levels were measured in sediment samples from the Kalamazoo River so the value was set at 1, indicating that 100% of the chemical was present in the sediment sample.
- The fraction of the area impacted with submerged oil (F_i) is the amount of the river with submerged oil. This value was 0.38, indicating that 38% of the river bottom had submerged oil. The 0.38 represents a quarter mile stretch in the Morrow Lake delta with the heaviest submerged oil footprint. Use of this value in the calculations provides the most conservative amount of oil that people may encounter (a worst-case scenario for exposure).
- The exposure frequency (EF) is the number of days per year a person is exposed to the chemicals in the sediment. To use the most conservative exposure scenario, 150 days were selected. This represents a daily exposure from May to October (spring to fall).
- The exposure duration (ED) is the number of years that residents may encounter these chemicals. To present the most conservative exposure scenario, all of the years within an age range were included.
- Sediment ingestion (IRS) refers to the amount of sediment that could be swallowed by children and adults. This includes accidental ingestion, such as hand-to-mouth behaviors

or eating without washing hands, and incidental ingestion of any sediment tracked in the house or yard. The MDEQ default value of 200 milligrams per day (mg/day) for children was used in the calculations (MDEQ 2005).

- Skin surface area (SA) refers to the amount of skin that is exposed that could have sediment sticking to it. The MDEQ default value of 2,670 square centimeters (cm^2) for children was used in the calculations (MDEQ 2005). This value represents children in shorts and a t-shirt, leaving the lower legs, feet, forearms, hands, and head exposed.
- Adherence factor (AF) refers to the amount of sediment that will adhere to a child's skin. The child value, 2.98 mg/cm^2, was calculated from a study of children playing in tidal flats. The sediment that adhered to various body parts (face, forearms, hands, lower legs, and feet) of the children was measured (EPA 2008). This value assumes that children wading in the river or walking through damp shoreline or wetlands would not have the sediment washed off from contact with the water.
- The conversion factor (CF) is a value that accounts for differences in the units used for the variables.
- Ingestion absorption efficiency (AE_i) is the amount of chemical that will be absorbed by the gastrointestinal tract after ingesting the chemical. This value was either a chemical-specific or default value (EPA 2004). The values for each chemical are in Table A-2.
- Dermal absorption efficiency (AE_d) is the amount of the chemical that can be absorbed through the skin. This value was either a chemical-specific or default value (MDEQ 2011). The values for each chemical are in Table A-2.
- The reference dose (RfD) is a chemical-specific value that is a conservative estimate of the daily intake that a human can have with minimal risk of adverse effects over a lifetime of exposure. The values for each chemical are in Table A-2.
- The averaging time is one year (365 days). This indicates that exposure is averaged over the whole year.
- Body weight is 15 kilograms (kg). This is the default MDEQ value for a child, ages 1-6 (MDEQ 2005).

Table A-2: Chemical-specific values for the hazard quotient calculation.

Chemical	Reference Dose (RfD) in milligrams/kilogram-day (mg/kg-day)	Gastrointestinal absorbance (AE_i)[a] (unitless)	Dermal absorbance (AE_d)[b] (unitless)
1,2,4-Trimethylbenzene	1.40E-01[b]	1	0.1
1,3,5-Trimethylbenzene	1.40E-01[b]	1	0.1
2-Methylnaphthalene	4.00E-03[c]	1	0.1
Acenaphthene	6.00E-02[c]	1	0.1
Acenaphthylene	7.10E-03[b]	1	0.1
Anthracene	3.00E-01[c]	1	0.1
Benzo(g,h,i)perylene	7.10E-03[b]	1	0.13
Beryllium	2.00E-03[c]	0.007	0
Ethylbenzene	1.00E-01[c]	1	0.1
Fluoranthene	4.00E-02[c]	1	0.1
Fluorene	4.00E-02[c]	1	0.1
Isopropyl benzene	1.10E-01[b]	1	0.1
Molybdenum	5.00E-03[b]	1	0.01
Naphthalene	2.00E-02[c]	1	0.1
Nickel	7.60E-02[b]	0.04	0.01
n-Propylbenzene	1.10E-02[b]	1	0.1
Phenanthrene	7.10E-03[b]	1	0.1
Pyrene	3.00E-02[c]	1	0.1
sec-Butylbenzene	1.10E-02[b]	1	0.1
Toluene	8.00E-02[c]	1	0.1
Vanadium	5.00E-03[b]	1	0.01
Xylenes	1.80E+00[b]	1	0.1

a = These values are from EPA (2004).
b = These values are from MDEQ (2011).
c = These RfDs are from the EPA Integrated Risk Information System (IRIS) database (http://www.epa.gov/iris/index.html; accessed June 2011).

Cancer risk

Theoretical cancer risk was calculated for the chemicals that are considered carcinogens and that have a slope factor (also called cancer potency factor). Two different types of carcinogens were included, those with an ADAF included in the cancer risk calculation and those without (EPA 2005). Theoretical lifetime excess cancer risk estimates are the probability of one additional case of cancer in an exposed population. For instance, a cancer risk may be one extra cancer in a population of 100,000 (1E-05)[14]. This extra cancer is in addition to the background cancer rates. This theoretical population risk estimate is not an actuarial risk that can be measured (e.g. annual deaths from motor vehicle accidents), but a probability estimate typically used by regulatory agencies and to support decision-making about when specific exposure reduction efforts are

[14] The MDEQ has a required cancer risk of no greater than one extra individual in 100,000 over the background incidence of cancer (MDEQ 2005) for regulatory purposes.

warranted. Typically, cancer risk estimates greater than one additional cancer in a population of 10,000[15] are used as a guideline to determine when intervention is needed.

Cancer risk for benzene

Benzene cancer risk was calculated for adults and children, ages 1-6, using Equation 2. Table A-3 and A-4 presents the variables for the benzene cancer risk calculation for an adult and child, respectively. Adult and child cancer risks for each sample were added together.

Equation 2: Benzene cancer risk - Ingestion and dermal risk equation[16]

$$Risk = \frac{Concentration \times F_{oil} \times F_i \times EF \times ED \times [IRS + (SA \times AF \times \frac{1}{AE_i} \times AE_d)] \times SF \times CF}{AT \times LT \times BW}$$

Table A-3: Variables used for calculation of benzene cancer risk for an adult with an unrestricted exposure scenario.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - adult	years	24
Sediment Ingestion (IRS) - adult	milligram per day (mg/day)	100
Skin surface area (SA) - adult	square centimeters (cm^2)	5,800
Adherence Factor (AF) - adult	milligram per square centimeter (mg/cm^2)	0.3
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Slope Factor (SF)	per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Lifetime (LT)	years	70
Body weight (BW) - adult	kilograms (kg)	70

Table A-4: Variables used for calculation of benzene cancer risk for a child, ages 1-6, with an unrestricted exposure scenario.

[15] Typically used ranges of cancer risk are from one extra cancer in 10,000 (1E-04) to one in 1,000,000 (1E-06).
[16] For the result to be unitless, skin surface area (SA) units need to cm^2/event and a variable for 1 event/day need to be included.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - child	years	6
Sediment Ingestion (IRS) - child	milligram per day (mg/day)	200
Skin surface area (SA) - child	square centimeters (cm^2)	2,670
Adherence Factor (AF) - child	milligram per square centimeter (mg/cm^2)	2.98
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Slope Factor (SF)	per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Lifetime (LT)	years	70
Body weight (BW) - child	kilograms (kg)	15

Variable descriptions are below:

- Concentration refers to the levels of the chemicals measured in each of the sediment samples. Concentration of each chemical is specific to the sample. If a chemical was detected above the reporting limit, that value was used in the calculations. If a chemical was not detected above the reporting limit, one-half of the reporting limit for that sample was used for the calculations.
- The fraction of the petroleum residue that is oil (F_{oil}) was used in the Gulf of Mexico oil spill to compensate for having analytical data on the oil and not the levels of chemicals present in the material on the beaches (OSAT-2 2011). Chemical levels were measured in sediment samples from the Kalamazoo River so the value was set at 1, indicating that 100% of the chemical was present in the sediment sample.
- The fraction of the area impacted with submerged oil (F_i) is the amount of the river with submerged oil. This value was 0.38, indicating that 38% of the river bottom had submerged oil. The 0.38 represents a quarter mile stretch in the Morrow Lake delta with the heaviest submerged oil footprint. Use of this value in the calculations provides the most conservative amount of oil that people may encounter (a worst-case scenario for exposure).
- The exposure frequency (EF) is the number of days per year a person is exposed to the chemicals in the sediment. To use the most conservative exposure scenario, 150 days were selected. This represents a daily exposure from May to October (spring to fall).
- The exposure duration (ED) is the number of years that residents may encounter these chemicals. To present the most conservative exposure scenario, all of the years within an age range were included.
- Sediment ingestion (IRS) refers to the amount of sediment that could be swallowed by children and adults. This includes accidental ingestion, such as hand-to-mouth behaviors or eating without washing hands, and incidental ingestion of any sediment tracked in the

house or yard. The MDEQ default values of 200 milligrams per day (mg/day) for children and 100 mg/day for adults were used in the calculations (MDEQ 2005).

- Skin surface area (SA) refers to the amount of skin that is exposed that could have sediment sticking to it. The MDEQ default values of 2,670 square centimeters (cm^2) for children and 5,800 cm^2 for adults were used in the calculations (MDEQ 2005). These values represent children and adults in shorts and a t-shirt, leaving the lower legs (and feet for children), forearms, hands, and head exposed.
- Adherence factor (AF) refers to the amount of sediment that will adhere to a child's or adult's skin. The child value, 2.98 mg/cm^2, was calculated from a study of children playing in tidal flats. The sediment that adhered to various body parts (face, forearms, hands, lower legs, and feet) of the children was measured (EPA 2008). The adult value, 0.3 mg/cm^2 represents adults working in the garden (MDEQ 2001). These values assume that children or adults wading in the river or moving through damp shoreline or wetlands would not have the sediment washed off from contact with the water.
- The conversion factor (CF) is a value that accounts for differences in the units used for the variables.
- Ingestion absorption efficiency (AE_i) is the amount of chemical that will be absorbed by the gastrointestinal tract after ingesting the chemical. This value was either a chemical-specific or default value (EPA 2004). The values for each chemical are in Table A-5.
- Dermal absorption efficiency (AE_d) is the amount of the chemical that can be absorbed through the skin. This value was either a chemical-specific or default value (MDEQ 2011). The values for each chemical are in Table A-5.
- The averaging time is one year (365 days). This indicates that exposure is averaged over the whole year.
- The slope factor (SF) is a chemical-specific value calculated by the EPA or the MDEQ to indicate the risk of cancer associated with exposure to a specific substance. The values for each chemical are in Table A-5.
- The lifetime (LT) value, 70 years, indicates that exposure to a chemical may impact a person over their lifespan.
- Body weight is 15 kg for children (ages 1-6) and 70 kg for an adult. These are the default MDEQ values (MDEQ 2005).

Table A-5: Chemical-specific values for the benzene cancer risk calculation.

Chemical	Slope factor (SF) in per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	Gastrointestinal absorbance (AE_i)[a] (unitless)	Dermal absorbance (AE_d)[b] (unitless)
Benzene	2.90E-02[b]	1	0.1

a = These values are from EPA (2004).
b = These values are from MDEQ (2011 T4).

Cancer risk for Polycyclic Aromatic Hydrocarbons (PAHs)

Cancer risk for the PAHs was calculated for adults and children (three age groups – 0-2, 2-6, and 6-16 years old) using Equation 3. Three separate age groups were used for the children's

calculations to add an additional variable, the Age-dependent Adjustment Factor (ADAF). The ADAF is included to account for age groups of children that may be more sensitive to these chemicals. The ADAFs and other variable are in Table A-5 (adult), A-6 (child ages 0-2), A-7 (child, ages 2-6), and A-8 (child, ages 6-16). Adult and child cancer risks for each chemical in a sample were added together.

Equation 3: Polycyclic Aromatic Hydrocarbons (PAHs) cancer risk - Ingestion and dermal risk equation[17]

$$Risk = \frac{Concentration \times F_{oil} \times F_i \times EF \times ED \times [IRS + (SA \times AF \times \frac{1}{AE_i} \times AE_d)] \times ADAF \times SF \times CF}{AT \times LT \times BW}$$

A cancer risk was calculated for these chemicals:

Benzo(a)pyrene
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Chrysene
Dibenzo(a,h)anthracene
Indeno(1,2,3-c,d)pyrene

[17] For the result to be unitless, skin surface area (SA) units need to cm^2/event and a variable for 1 event/day need to be included.

Table A-6: Variables used for calculation of Polycyclic Aromatic Hydrocarbons (PAHs) cancer risk for an adult with an unrestricted exposure scenario.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - adult	years	14
Sediment Ingestion (IRS) - adult	milligram per day (mg/day)	100
Skin surface area (SA) - adult	square centimeters (cm^2)	5,800
Adherence Factor (AF) - adult	milligram per square centimeter (mg/cm^2)	0.3
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Age-dependent adjustment factor (ADAF) - adult	Unitless	1
Slope Factor (SF)	per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Lifetime (LT)	years	70
Body weight (BW) - adult	kilograms (kg)	70

Table A-7: Variables used for calculation of Polycyclic Aromatic Hydrocarbons (PAHs) cancer risk for a child, age 0-2, with an unrestricted exposure scenario.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - child	years	2
Sediment Ingestion (IRS) - child	milligram per day (mg/day)	200
Skin surface area (SA) - child	square centimeters (cm^2)	2,670
Adherence Factor (AF) - child	milligram per square centimeter (mg/cm^2)	2.98
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Age-dependent adjustment factor (ADAF) - child	Unitless	10
Slope Factor (SF)	per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Lifetime (LT)	years	70
Body weight (BW) - child	kilograms (kg)	10

Table A-8: Variables used for calculation of Polycyclic Aromatic Hydrocarbons (PAHs) cancer risk for a child, age 2-6, with an unrestricted exposure scenario.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - child	years	4
Sediment Ingestion (IRS) - child	milligram per day (mg/day)	200
Skin surface area (SA) - child	square centimeters (cm^2)	2,670
Adherence Factor (AF) - child	milligram per square centimeter (mg/cm^2)	2.98
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Age-dependent adjustment factor (ADAF) - child	Unitless	3
Slope Factor (SF)	per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Lifetime (LT)	years	70
Body weight (BW) - child	kilograms (kg)	15

Table A-9: Variables used for calculation of Polycyclic Aromatic Hydrocarbons (PAHs) cancer risk for a child, age 6-16, with an unrestricted exposure scenario.

Variable	Unit for the variable	Value for the variable
Concentration	milligram per kilogram (mg/kg)	Sample and chemical-specific
Fraction of petroleum residue that is oil (F_{oil})	Unitless	1
Fraction of area impacted with submerged oil (F_i)	Unitless	0.38
Exposure Frequency (EF)	days/year	150
Exposure Duration (ED) - child	years	10
Sediment Ingestion (IRS) - adult	milligram per day (mg/day)	100
Skin surface area (SA) - adult	square centimeters (cm^2)	5,800
Adherence Factor (AF) - adult	milligram per square centimeter (mg/cm^2)	0.3
Gastrointestinal absorbance (AE_i)	Unitless	chemical-specific
Dermal absorbance (AE_d)	Unitless	chemical-specific
Age-dependent adjustment factor (ADAF) - child	Unitless	3
Slope Factor (SF)	per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	chemical-specific
Conversion factor (CF)	kilogram per milligram (kg/mg)	1/1,000,000
Averaging Time (AT)	days/year	365
Lifetime (LT)	years	70
Body weight (BW) - child	kilograms (kg)	50

Variables descriptions are below:

- Concentration refers to the levels of the chemicals measured in each of the sediment samples. Concentration of each chemical is specific to the sample. If a chemical was detected above the reporting limit, that value was used in the calculations. If a chemical was not detected above the reporting limit, one-half of the reporting limit for that sample was used for the calculations.
- The fraction of the petroleum residue that is oil (F_{oil}) was used in the Gulf of Mexico oil spill to compensate for having analytical data on the oil and not the levels of chemicals present in the material on the beaches (OSAT-2 2011). Chemical levels were measured in sediment samples from the Kalamazoo River so the value was set at 1, indicating that 100% of the chemical was present in the sediment sample.
- The fraction of the area impacted with submerged oil (F_i) is the amount of the river with submerged oil. This value was 0.38, indicating that 38% of the river bottom had submerged oil. The 0.38 represents a quarter mile stretch in the Morrow Lake delta with the heaviest submerged oil footprint. Use of this value in the calculations provides the most conservative amount of oil that people may encounter (a worst-case scenario for exposure).
- The exposure frequency (EF) is the number of days per year a person is exposed to the chemicals in the sediment. To use the most conservative exposure scenario, 150 days were selected. This represents a daily exposure from May to October (spring to fall).
- The exposure duration (ED) is the number of years that residents may encounter these chemicals. To present the most conservative exposure scenario, all of the years within an age range were included.
- Sediment ingestion (IRS) refers to the amount of sediment that could be swallowed by children and adults. This includes accidental ingestion, such as hand-to-mouth behaviors or eating without washing hands, and incidental ingestion of any sediment tracked in the house or yard. The MDEQ default values of 200 milligrams per day (mg/day) for children and 100 mg/day for adults were used in the calculations (MDEQ 2005).
- Skin surface area (SA) refers to the amount of skin that is exposed that could have sediment sticking to it. The MDEQ default values of 2,670 square centimeters (cm^2) for children and 5,800 cm^2 for adults were used in the calculations (MDEQ 2005). These values represent children and adults in shorts and a t-shirt, leaving the lower legs (and feet for children), forearms, hands, and head exposed.
- Adherence factor (AF) refers to the amount of sediment that will adhere to a child's or adult's skin. The child value, 2.98 mg/cm^2, was calculated from a study of children playing in tidal flats. The sediment that adhered to various body parts (face, forearms, hands, lower legs, and feet) of the children was measured (EPA 2008). The adult value, 0.3 mg/cm^2 represents adults working in the garden (MDEQ 2001). These values assume that children or adults wading in the river or moving through damp shoreline or wetlands would not have the sediment washed off from contact with the water.
- The conversion factor (CF) is a value that accounts for differences in the units used for the variables.
- Ingestion absorption efficiency (AE_i) is the amount of chemical that will be absorbed by the gastrointestinal tract after ingesting the chemical. This value was either a chemical-specific or default value (EPA 2004). The values for each chemical are in Table A-10.

- Dermal absorption efficiency (AE_d) is the amount of the chemical that can be absorbed through the skin. This value was either a chemical-specific or default value (MDEQ 2011). The values for each chemical are in Table A-10.
- The averaging time is one year (365 days). This indicates that exposure is averaged over the whole year.
- The age-dependent adjustment factor (ADAF) is additional safety factor included in the calculations to account for children's increased sensitivity to effects from these carcinogens.
- The slope factor (SF) is a chemical-specific value calculated by the EPA or the MDEQ to indicate the risk of cancer associated with exposure to a specific substance. The values for each chemical are in Table A-10.
- The lifetime (LT) value, 70 years, indicates that exposure to a chemical may impact a person over their lifespan.
- Body weight is 15 kg for children (ages 2-6) and 70 kg for an adult. These are the default MDEQ values (MDEQ 2005). Body weight for children ages 0-2 is 10 kg and 50 kg for children ages 6-16. These body weights are based on the body weight averages (EPA 2008).

Table A-10: Chemical-specific values for the Polycyclic Aromatic Hydrocarbons (PAHs) cancer risk calculation.

Analyte	Slope factor (SF) in per milligram per kilogram-day ($[mg/kg\text{-}day]^{-1}$)	Gastrointestinal absorbance (AE_i)[a] (unitless)	Dermal absorbance (AE_d)[b] (unitless)
Benzo(a)pyrene	7.30E+00	1	0.13
Benzo(a)anthracene	7.30E-01	1	0.13
Benzo(b)fluoranthene	7.30E-01	1	0.13
Benzo(k)fluoranthene	7.30E-02	1	0.13
Chrysene	7.30E-03	1	0.13
Indeno(1,2,3-c,d)pyrene	7.30E-01	1	0.13
Dibenzo(a,h)anthracene	7.30E+00	1	0.13

a = These values are from EPA (2004).
b = These values are from MDEQ (2011).
c = The benzo(a)pyrene slope factor is from the EPA Integrated Risk Information System (IRIS) database (http://www.epa.gov/iris/index.html; accessed June 2011). Slope factors for other PAHs are based on the benzo(a)pyrene relative potencies (http://www.epa.gov/oswer/riskassessment/sghandbook/pdfs/pah-rpfs.pdf).